# Research on The Literature of Green Buildingbased on The Web of Science: A Scientometricanalysis in Citespace(2002–2018)

**Tamal Sur Chowdhury[1], Sourabh Shukla[2], Azhar Mazhar Baig[3]**
[1, 2] Dept of MBA(Project & Construction Management)
[1, 2] MIT ADT University, Pune-412201, Maharashtra (INDIA)

***Abstract-*** *Since the 21st century, the concept of green building has been gradually popularized and implemented in additional countries, which has become a well-liked direction within the area of sustainability within the building industry. Over the past few years, many scholars and engineers have done extensive research on green building. the aim of this paper is to systematically analyze and visualize the established order of green building. On the idea of aforementioned keywords, clusters, and citation bursts analysis, this paper has built a knowledge graph for green building. This paper can help readers to raised understand the established order and development trend of green building and to easier recognize the shortcomings within the development of green building, so on provide a promising direction for future research.*

***Keywords***- Literature review, green building, visualized analysis, citespace

## I. INTRODUCTION

With the rapid development of the economy and society, the shortage of energy and the deterioration of environment have become two major problems faced by human beings in today's society. At present, the construction industry is the prior source of consumption of world energy sources and various kinds of resources like ores, wood, and so on, as well as the major source of environmental pollution. According to the United Nations Environment Programme (UNEP), energy consumption in the building industry accounts for about 30–40% of the world's energy consumption. China's energy consumption is among the highest in the whole world, and the consumption of the building industry accounts for 38% of the total social energy consumption. Faced with a grim situation, the transformation and upgrading of the building industry is imminent. However, it is difficult for the industry to figure out a green, environmentally friendly, and sustainable road for development. Therefore, there is a crying need for exploring and establishing the sustainable development mode of the building industry in order to transform the current situation of high resource consumption and high environmental pollution.

With the rapid development of computing technology and information visualization technology, scholars can discover the hidden relations and trends in the relevant literature. For example, document co-citation analysis, which searches for relations among documents, has been used by many scholars to draw and create research knowledge structures. The combination of quantification and visualization can help us to further understand the knowledge in the specific area.

CiteSpace is a diverse, time-sharing, and dynamic analysis software for visualizing citations with the development of scientometrics, as well as data and information visualization technologies, aiming at analyzing the underlying knowledge contained in scientific literature. CiteSpace effectively helps readers to raised understand the areas of research during which they're engaged. It can not only show the whole situation of a certain research field, but also highlight some important documents in the development of the field. It has been launched tens of thousands of times in at least 60 countries, and has been continuously upgraded and updated with high reliability, making it a new tool widely used in scientometrics.

Building Services Research and Information Association (BSRIA) considers that the creation and management of a healthy building environment should be based on the principles of high-efficient resource utilization and ecological benefits. The Building Energy Efficient Research, University of Hong Kong defines that the environmental design of green building is the overall design of buildings; all resources should be taken into consideration for sustainable buildings, including materials, fuels, or users themselves; green building involves many problems and contradictions that need to be solved and every part of design will have an impact on the environment. According to the national conditions of China and the concept of sustainable development, the Ministry of Housing and Urban-Rural

Development issued Assessment Standard for Green Building on 1 June 2006, and made a definition as follows: Green building refers to maximizing the resources conservation including energy, land, water, materials, and so on; protecting the environment and reduce pollution; providing healthy, applicable, and efficient living room for people; and coexisting harmoniously with nature in the life-cycle of the building.

## II. RESEARCH METHOD

The paper explains the existing research on green building based on the literature from 2002 to 2018 in WoS using CiteSpace. This paper can help readers to systematically understand the co-citation documents, key clusters, and keywords, as well as the knowledge evolution pattern of green building from the related literature. Although there is no detailed analysis of all literature related to green building, this paper quantitatively summarizes the status quo and development trend of green building in view of its high reference value of the sample literature.

The contents of this study include the following:

a) Using the functions of document co-citation analysis, cluster analysis, and keyword co-occurrence analysis of CiteSpace, this paper analyzes the literature of green building from 2002 to 2018, to obtain the knowledge base and knowledge domain of green building;
b) By Identifying the knowledge evolution pattern of green building using citation burst detection;
c) On the basis of the knowledge base (which consists of keywords related to the research topic), knowledge domain (which is related to key research fields of the research topic), and knowledge evolution (which is an evolutionary process reflected by references with citation bursts), a knowledge graph for green building is built.

### 1.1 Data Collection

Two keywords, green building and sustainable building, are used for retrieval in different databases, and the number of collected documents is shown as follows: 15,800 in Google Scholar, 7962 in Scopus, 7201 in Springer, 6759 in EI, and 3758 in WoS. The data analyzed by CiteSpace are based on WoS data, and the data collected by other databases must be converted into the data format of WoS before being analyzed. Some data may be incompatible in the conversion process and have an impact on the following analysis. Besides, each record for a document in the CiteSpace has a fixed format, while the document data fields of other databases may be incomplete, increasing the noise of the source data. However, WoS fully covers the most important and influential academic research achievements in the world, and has been widely applied in the past review research, with great reference value.

### 1.2 Data Analysis

The bibliographic map of green building can be illustrated by various kinds of networks such as co-authors, co-cited documents, co-occurrence keywords, and so on, which can be built by CiteSpace. In this paper, we mainly analyze the following aspects including document co-citation network, clustering network, keyword co-occurrence network, and knowledge evolution pattern of green building.

They refer to the relatively frequent-cited documents in the field of research, which are generally considered to be fundamentally important references to the research. If there are two documents often being co-cited, they may relate to a similar concept. By clusters of statistics, a group of closely related documents can be identified and then aggregated into clusters according to their interconnectivities. Each cluster represents a different knowledge domain, and the same cluster represents the same research domain. Furthermore, the interactions of clusters can reflect their correlation. Keyword co-occurrence network is used to detect keywords that appear in at least two different documents within a time period. As pivotal hotspots in corresponding time periods, these high-frequency keywords and central keywords can be regarded as part of the knowledge base of green building. At present, the knowledge base and knowledge domain of green building are of great importance in conducting research. It is very helpful to identify references with strong citation bursts using CiteSpace. The nodes of strong bursts signify that these documents have received special attention in the corresponding time periods, which can show the frontiers and hotspots of the discipline to a certain extent.

### 1.3. Results of Citation Analysis

#### 1.3.1. Knowledge Domain in the Core Database

#### 1.3.2. Document Co-Citation Analysis

On the idea of the visualized analysis of 3147 documents within the core database with CiteSpace, we will obtain a co-citation network of 1693 nodes and 62,565 links. The larger the node, the upper frequency of citation of the document, indicating that the document is of great importance within the green building discipline. The timeline from 2002

to 2018 will be sliced into a series of time periods by CiteSpace, with every two years in each slice. The top 50 documents with the highest frequency of citation in each time period are selected for co-citation analysis, and then a co-citation network is generated. The top 10 frequent co-cited documents from the network are chosen for the further analysis.

The popularization of green building also faces some challenges. Robichaud and Anantatmula analyzed green building from two aspects of construction cost and development trend, and figured out the existing difficulties (e.g., the ability of a contractor to handover greening projects under acceptable cost constraints) in the constantly expanding green building market, and proposed detailed modifications to greening project management practices. Hwang and Tan summarized the research progress in the field of green building in recent years, analyzed the energy consumption of green building projects and its impact on the natural environment, called on the whole society to take necessary measures, and promoted the sustainable development of green building. Zhang et al. discussed the costs and barriers of applying green technology to green property development practice in China. By analyzing the additional cost of green buildings, it was concluded that the main barrier to promoting green technology in China is the high cost.

**1.3.3) Cluster Identification and Analysis (Knowledge Domain)**

Identifying highly cited documents by document co-citation analysis is the first step in building a knowledge domain, and the second step is to analyze documents so as to figure out the key research domain. A cluster label is selected from the noun phrases of each cluster. The noun phrases are extracted from the title, keywords, and abstract of documents, and the top-ranked phrases will be likely to be chosen as cluster labels.

CiteSpace provides three different types of cluster labeling extraction algorithms, including log-likelihood ratio (LLR) test, term frequency-inverse document frequency (TF IDF) and mutual information (MI) test. In this paper, LLR test, the default algorithm of CiteSpace, was used to extract the cluster labels. In statistics, a likelihood ratio test is a statistical test used for comparing the goodness of fit of two statistical models—a null model against an alternative model. Thtest is based on the likelihood ratio, which expresses how many times more likely the data are under one model than the other. This likelihood ratio, or equivalently its logarithm, can then be used to compute a p-value, or compared to a critical value to decide whether or not to reject the null model.

The below figure illustrates the clusters generated by CiteSpace. The number of the largest cluster is No. 0, and the number of the smallest one is No. 4. The size of a cluster depends on the total number of published papers that the cluster contains

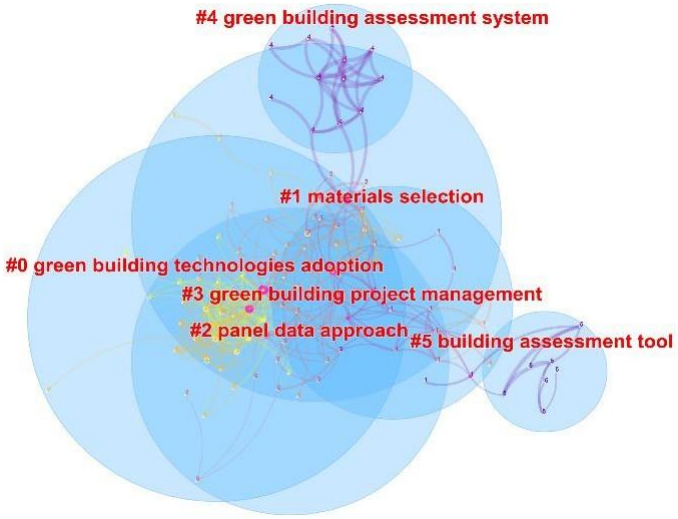
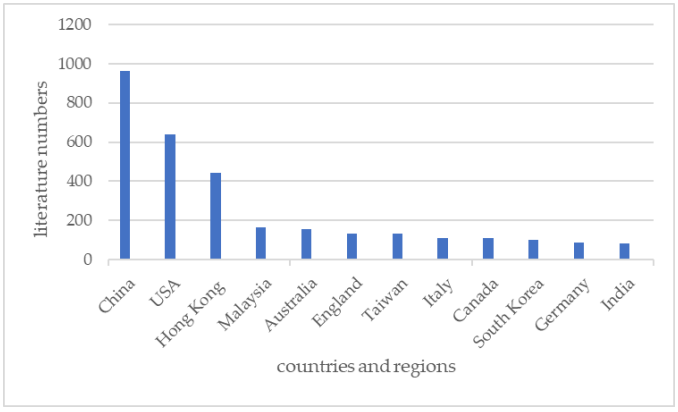



**Figure :**Clusters of knowledge domain within green building

**1.3.4) Keyword Co-Occurrence Network (Knowledge Base)**

Because of the close relation between the keywords and the cores of documents, the analysis of similar keywords can help to identify the cores of green building research. The terms are being grouped hereinafter, for example, green building, sustainable building, and sustainable construction can be divided into one category. It can be seen that the font size of keywords is proportional to the co-occurrence frequency of the keywords.




Modeling and simulation are important research key points with a co-occurrence frequency of 197 times. Green building has considerable connotations and should be managed with the help of modern information technology. Building information modeling (BIM) technology can replace the traditional two-dimensional drawings with the three-

dimensional visualized model, improves the design efficiency and the quality of drawing review, and can find errors in the construction drawings more quickly and correctly in time. At the same time, it can simulate every construction process in advance through the three-dimensional model, which will optimize the construction procedures and facilitate communication with all parties of the project. Modeling and simulation are needed throughout the life-cycle of the building from design to construction, and operation.

Design (sustainable design) is also an important research focus of green building with a co-occurrence frequency of 175 times. Ensuring the health of residents is the priority of green building design. It should be aware of reducing impacts on the natural environment and designing energy conservation buildings that meet the principles of system synergy, territoriality, high efficiency, nature protection, health, economy, and evolution. Some scholars argue that both economic and environmental benefits should be taken into consideration in designing green buildings. Now, the construction industry vigorously promotes the optimization design of green buildings; emphasizes on obeying the laws of nature and maintains ecological balance; integrates the social, cultural, and psychological needs of people into the building design; and constructs harmonious and healthy green buildings

China, the United States, and Hong Kong are hot spots with a cumulative co-occurrence frequency of 160 times. Data show that China has been the largest LEED-certified market outside the United States since 2010, accounting for 9% of the global LEED-certified area, and 32% of the certified area outside the United States. By August 2017, China had a complete LEED-certified area of 48 million square meters, covering 54 cities. Hong Kong set up its first green building certification system of HK BEAM (Hong Kong Building Environment Assessment Method) in 1996. According to the statistics of Hong Kong Green Building Council (HKGBC), there are 1236 projects in Hong Kong that have passed the green building certification Since 1 April 2011, the green building environment assessment certification has become a gift incentive. According to data released by the China Real Estate Association, there were 10,927 green building projects nationwide by the end of December 2017, with an increase of more than 3000 from the previous year, and a green buildings' area of more than 1 billion square meters. Figure5shows the results of 3147 documents retrieved from the WoS core database, ranked by countries and regions. It can be found that scholars from China, the United States, and Hong Kong pay more attention and conduct more research on green building.

Life cycle assessment, or LCA, with a co-occurrence frequency of 156 times, quantifies the material flows and energy consumption flows of every stage of the life-cycle (from raw material acquisition to design, manufacture, utilization, recycling, and final disposal, among others), gives quantitative assessment to the life-cycle of building system and the regional environment, and figures out methods of improvement to provide the basis of analysis and decision-making for all stakeholders in the construction industry. With the development of green building, accelerating the green transformation of industry including the construction industry has become an important mission for China's "green development". As a tool to comprehensively assess the green level of products, LCA has been recognized worldwide and has become an important support for the development of green building in various countries.

The assessment standards are not the same for different types of buildings. Therefore, the type of building is also a research focus that cannot be neglected. The co-occurrence frequency of residential building/office building is 149. It is helpful to solve the existing problems in the construction industry by fully considering the types of building. At present, there are only two kinds of objects in the Assessment Standard for Green Building in China, namely, residential building and public building. If all buildings are assessed according to the two green building assessment standards, it is impossible to carry out a scientific and comprehensive analysis of the building. Therefore, during the process of perfecting the green building assessment standards in China, it is necessary to further refine the types of buildings and divide them into different categories according to the actual developments of the construction industry and the national conditions of China, in order to carry out a scientific and comprehensive analysis on the buildings.

The environmental impact and climate change produced in the construction process are also worth noticing. The new-built constructions, reconstructions, and demolition of buildings will result in the waste of resources and energy consumption, as well as a large amount of solid waste, and finally pollute the environment. The construction industry has been a leading carbon emitter for a long time. The simultaneous growth of building size, volume, and energy consumption intensity will inevitably bring tremendous carbon emission, which will be the focus of the further studies of energy conservation and emission reduction work in China. Therefore, green buildings fully incorporate the green concept into the construction process, and adopt various kinds of low-carbon and environmentally friendly materials to reduce the energy consumption and improve the construction technical

level of the project, which can effectively alleviate the current situation.

After meeting the basic residential needs for shelters from wind and rain, people start to pay increasing attention to the needs for living comfortably and healthily. Thermal comfort is a complex process of dynamic adjustment of temperature and humidity. The satisfaction of building users is closely related to thermal comfort; meanwhile, the other factors of psychology, physiology, culture or behavior of people may also react to thermal comfort. Green buildings in the future should take into full consideration the climate, indoor environmental quality, and natural ventilation to create a healthy and comfortable residential environment. It is found that the health status and productivity level of people will be improved when they are working and living in green buildings. The study shows the impacts of green buildings on productivity and absenteeism cannot be ignored.

The development of green building also comes with many challenges. Although green building seems to be more attractive from an environmental point of view, the costs are far higher than those of traditional building. In addition, some scholars have questioned the overwhelming superiority of green building in thermal comfort. For example, Paul and Taylor discovered that there is no significant difference in terms of thermal comfort between green buildings and traditional buildings equipped with heating, ventilation, and air conditioning systems.

**2) Knowledge Graph For Green Building**

The knowledge base, knowledge domain, and knowledge evolution of green building are clearly visualized and analyzed using the method of bibliometrics, and are integrated to build a green building knowledge graph, as shown in Figure.

As can be seen from Figure, the knowledge graph for green building is composed of the knowledge base, knowledge domain, and knowledge evolution. The green building knowledge base includes keywords identified by the co-occurrence network. The green building knowledge domain is identified by cluster analysis, which can help us better understand the main research fields of green building, including technology adoption, material selection, panel data method, green building project management, and green building assessment system (building assessment tools). These clusters are further divided into the technical system, the management system, and the assessment system. Among them, the technical system refers to the relevant technical means adopted within the life-cycle of building so as to satisfy the wants of green building; the assessment system refers to a set of objective, fair, and local index system and assessment methods that can be quantitatively evaluated in order to promote real green building; and green building project management includes scope management, time management, cost management, quality management, schedule management, human resources management, communication management, risk management, procurement management, integrated management and so on. These three systems are effective pillars for the graceful implementation of green building. The knowledge evolution of green building is briefly shown as follows. In the early stages of green building development, most of the attention is focused on cost and benefits (2005–2011) and environmental quality (2006–2013); with the development of the construction industry, material selection (2011–2013), energy efficiency (2011–2015), lean production (2013–2014), energy saving (2013–2016), optimal design (2012–2016), and information technology (2013–2016) have become the research focuses. It is worth noting that the assessment system for green buildings received extensive attention in both time periods of 2012–2016 and 2008–2015.

Through analyzing the knowledge base, knowledge domain, and knowledge evolution of green building, the knowledge frame and development process of the green building discipline can be understood. Green building is a rapidly developing domain, thus the knowledge base, knowledge domain, and knowledge evolution model may change in the future. The relevant technologies and assessment tools for green buildings should be changed accordingly. For example, the establishment of BIM for green building via advanced modern information technology will play an important role in the development of green building. By reading a large number of documents, it is found that BIM technology has not been fully applied in the project operational stage, and the integrated optimization of BIM is still imperfectly applicable to the green building certification system. Therefore, realizing the collaborative management of BIM in each stage is that the key of future research. In addition, it will be the main development trend in the future to incorporate modern information technology, services, and management as a whole, and to provide a more convenient, safer, and energy-saving living environment for people in terms of building construction.

## III. CONCLUSIONS

On the basis of 3147 articles in the core database and 3758 articles in the extended database related to green building, this paper analyzed the existing knowledge system of

green building using CiteSpace, and obtained the following results.

a) As shown in Table, this paper identified the keywords of the green building knowledge base using the function of keyword co-occurrence analysis, among which green building, sustainable development, construction, performance, energy, assessment tools, and other 60 keywords are relatively important.
b) As shown in Figure, five major clusters including the green building technologies adoption, materials selection, panel data approach, green building project management, and green building assessment system were recognized and can be further divided into the technical system, the management system, and the assessment system using cluster analysis, which can be regarded as the knowledge domain of green building.
c) As shown in Figure, the knowledge evolution of green building was analyzed by using citation bursts, revealing how research related to green building has evolved over time.

The unique value of this paper is to build a knowledge graph for green building based on keywords, clusters, and citation bursts using the function of quantitative analysis of CiteSpace. In the future, the data can be updated regularly to carry out relevant research, so that we can further improve the green building knowledge graph provided by this study.

**Author Contributions:** Y.S. contributed to the conception and design. X.L. performed research and analyzed the data.

**Funding**: This research received no external funding.

## REFERENCES

[1] Bhutta,F.M.Applicationofsmartenergytechnologiesinbuildingsector-futureprospects.InProceedingsof the2017InternationalConferenceonEnergyConservationandE*ffi*ciency(ICECE),Lahore,Pakistan,22–23 November 2017; pp.7–10.
[2] Abdallah,M.;El-Rayes,K.;Liu,L.Optimizingtheselectionofsustainabilitymeasurestominimizelife-cycle cost of existing buildings. *Can. J. Civ. Eng.* **2016**, *43*, 151–163.[CrossRef]
[3] Lu,Y.;Peng,C.;Li,D.WhichactivitiescontributemosttobuildingenergyconsumptioninChina?Ahybrid LMDI decomposition analysis from year 2007 to 2015. *Energy Build.* **2018**, *165*, 259–269.[CrossRef]
[4] Chatterjee,D.K.WorldCommissiononEnvironmentandDevelopment.*Environ.PolicyLaw***1987**,*14*,26–30.
[5] McCammon,A.L.UnitedNationsConferenceonEnvironmentandDevelopment,heldinRiodeJaneiro,Brazil, during3–14June1992,andthe'92GlobalForum,RiodeJaneiro,Brazil, 1–14June1992.*Environ.Conserv.***1992**,*19*, 372–373.[CrossRef]
[6] Strong,M.F.*TheGlobalPartnershipforEnvironmentandDevelopment.AguidetoAgenda21*;TheUnitedNations Conference on Environment and Development: Rio de Janeiro, Brazil,1992.
[7] Alawneh, R.; Ghazali, F.; Ali, H.; Asif, M. A new index for assessing the contribution of energy e*ffi*ciency in LEED 2009 certified green buildings to achieving UN sustainable development goals in Jordan. *Int. J. Green Energy* **2019**, *16*, 490–499.[CrossRef]
[8] Darko, A.; Chan, A.P.C.; Yang, Y.; Shan, M.; He, B.J.; Gou, Z.H. Influences of barriers, drivers, and promotion strategies on green building technologies adoption in developing countries: The Ghanaian case. *J. Clean. Prod.***2018**, *200*, 687–703.[CrossRef]